TU HAMBURG-HARBURG

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Test Report

Test for the Resistance of ®MOWILITH-Modified Pipe Concretes with CEM I 42.5 R HS NA when Exposed to pH 2 Sulphuric Acid and pH 3.2 to pH 3.5 Lactic Acid

Customer:

Clariant GmbH

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A publication of this report – even excerpts of it – requires the express approval of the author.

1. Test Order

The undersigned was commissioned by Clariant GmbH to test the extent to which the use of the concrete additive [®]MOWILITH LDM 6880 can increase the corrosion resistance of pipe concretes to acids. In particular, the corrosion resistance to biogenic sulphuric acids was to be determined. In addition, the corrosion resistance to organic acids, such as those that occur in the agriculture and food-processing industries, was to be calculated.

The product [®]MOWILITH LDM 6880 has been approved as a concrete additive according to DIN 1045 by the German Institute for Construction Engineering under the test mark Z-3.38-1297 (formerly Z-Pa VII-21/802).

The tests were conducted for 400 days in sulphuric acid with a pH value of 2 and for 6 or 8 months in lactic acid at pH values of 3.2 - 3.5 as an aggressive medium as outlined in the "Guideline for the Testing of Mortars for Use in Sewer System Construction" [1] published by the undersigned.

The concrete composition of the pipe concretes was established together with the customer, Bauberatung Zement Hamburg and the institute of the undersigned. The recipe and processing characteristics are oriented towards common practice. A cement of the CEM I 42.5 R HS NA class was used that is normally employed for manufacturing pipe concretes when there are increased demands with regard to corrosion resistance. Two basic recipes were prepared, for which Rhine gravel and sand on the one hand and double screened limestone chippings and sand on the other were used as the aggregate. The grain-size distributions of both aggregate types were the same. The test specimens were produced under laboratory conditions.

In order to demonstrate the efficacy of the concrete additive, both basic recipes were subjected to comparative testing with and without [®]MOWILITH LDM 6880. In the process, the water/cement value and the cement percentage were kept constant each time.

The consistency of the unmodified concretes with the versions modified exclusively with [®]MOWILITH was brought about using concrete liquefier and plasticiser. When calculating the material volume, the [®]MOWILITH construction material dispersion was factored in as an aggregate and counted as water when calculating the W/C value.

2. Abbreviations Used

The different mixtures have been labelled with the following abbreviations:

	Abbreviation	Meaning
1 st position	R	Pipe concrete
2 nd position	K or Q	Limestone (German: <i>Kalkstein</i>) or quartzite aggregate
3 rd position	HS	CEM I 42.5 R HS NA cement
4 th position	0 or 1	Without [®] MOWILITH or with [®] MOWILITH
5 th position	-1 to -20	Test specimen number

Table 1: Abbreviations of the concrete test specimens

3. Producing the Test Specimens, Fresh and Hardened Concrete Characteristics before Placement

3.1. Cement Used

CEM I 42.5 HS NA (Sulfadur Doppel) manufactured by Dyckerhoff was used to produce the concretes.

3.2. Aggregate Used

When producing the concretes, a quartzite Rhine gravel and sand resistant to acids was used on the one hand and double screened limestone sand and chippings sensitive to acids were procured on the other. The limestone comes from the Kaltes Tal lime plant (stone plant). The aggregates delivered were dried to core moisture and sieved into the fractions.

The grain-size distribution of the aggregate was composed in collaboration with the customer, the Bauberatung Zement and the undersigned. The grain fractions and the grain-size distribution used for the pipe concretes are shown in Table 2 and further below in Diagram 1.

 Table 2:
 Sieving of the aggregates for the pipe concretes

Mesh Width	0.125	0.25	0.5	1	2	4	8	16	K
Sieving [%] Grain-size distribution of the pipe concretes	2	5	11	20	29	39	65	100	4.31



Diagram 1: Target grain-size distribution of the aggregates for the pipe concretes. The grain distribution was selected in consultation with Clariant GmbH, the Bauberatung Zement Hamburg and the TUHH. Normal grain-size distributions A16 and B16 are also shown.

3.3. Mixture Preparations

The mixture preparations for the pipe concretes are shown in Table 4 and the applicable material constants for all components in Table 3.

Water/cement value	0.35		
Dispersion/cement value Dispersion density Artificial resin density (calculated)	0.15 1.04 kg/dm ³		
Dispersion water content	approx. 50% (weight)		
Aggregate	Double screened limestone chippings and crushed sand / quartz gravel and sand		
Aggregate density	2.65 kg/l		
Content of the mixtures	350 kg/m ³		
Binding agent density:			
CEM I 42.5 R HS NA	3.2 kg/dm ³		

 Table 3:
 Applicable boundary conditions and material constants for all mixtures

Table 4:Mixture preparations for the pipe concretes in kg. The mixtures are calculated for 23 litres of
concrete each and for an assumed air void content of 1.5%.

	Without [®] M	OWILITH	With [®] MOWILITH					
	R K HS 0	R Q HS 0	R K HS 1	R Q HS 1				
1 m ³ preparation	1 m ³ preparation							
Cement	Cement 350.0							
Aggregate	19	996	1922					
Water	122	2.50	96.25					
Dispersion	-	/-	52.50					
23 1-preparation								
Cement	8.050							
Aggregate	45	.46	44.21					
Water	2.	2.82 2.21						
Dispersion	-	/-	1.207					

The calculated quantity of each aggregate fraction for producing 23 litres of concrete was weighed and put into a compulsory mixer. The cement was also added, after which the aggregate and cement were premixed for 3 minutes to ensure that the cement distribution was as homogeneous as possible. Then approx. 90 per cent of the calculated water mass (W/C = 0.35 was the goal) were added. For the [®]MOWILITH-modified mixtures, the additive was dispersed in this quantity of water. The concrete continued to be mixed according to standard practice. If the required consistency did not yet appear to have been reached, water was added until the W/C of 0.35 was attained. If the water was not sufficient, the consistency of the unmodified mixture was adjusted with BV 1 concrete liquefier. The amount of BV 1 (Addiment) that needs to be added is specified in per cent of cement weight. The deviations in the W/C between the R K HS 0 and R K HS 1 mixtures is due to the highly liquifying effect of [®]MOWILITH. The desired degree of compaction for the mixtures was taken as the basis for using the mixture. The quantity of concrete liquefier added was the highest admissible dose.

Ten minutes after mixing was started, the degree of compaction V_{10} was calculated. The values for this are documented in Table 5. If it was in the required range, the concrete was poured into the moulds. The test specimens were compacted on a high-capacity vibrating table on which the moulds were firmly clamped. After being filled, the concrete was compacted with a compaction weight (0.02 N/mm²) until sagging of the concrete was no longer observed.

Table 5 shows the green compressive strength β_G in addition to the calculated raw densities of the mixtures. The green compressive strength was determined directly (approx. 10 minutes) after the test specimens were compacted. Required was a green compressive strength of 0.1 N/mm² so that such a recipe can be used in practice for producing concrete pipes. The pipes are generally removed from the moulds directly after being compacted. All mixtures could have been used in pipe production based on the green compressive strengths calculated.

Designation	BVI	W/C	V10	Pipe D.	βG	
	%			kg/l	N/mm ²	
Without [®] MOWILITH						
R K HS 0	0.4	0.35	1.498	2.541	0.3	
R Q HS 0	0.4	0.35	1.404	2.453	0.1	
With [®] MOWILITH						
R K HS 1	-	0.31	1.510	2.541	0.1	
R Q HS 1	-	0.35	1.25	2.462	0.09	
BV1 = Addiment concrete liquefier (German: Betonverflüssiger); V10 = degree of compaction (German:						

 Table 5:
 Fresh concrete characteristics and selected mixture components of the pipe concretes.

BV1 = Addiment concrete liquefier (German: *Betonverflüssiger*); V_{10} = degree of compaction (German *Verdichtungsmaß*) after 10 minutes;

 β_{G} = Green compressive strength 10 minutes after being put into the mould

4. Conducting and Assessing the Tests on Acid Resistance

4.1. Execution

After cutting, the test specimens were left in the mould for 2 days, removed from the mould and then stored for 6 days under water. On the 7th day, they were measured and stored at 23 °C and 50% rel. humidity until they were 80 days old. On the 84th day, after being stored in water for 4 days, 4 cylinders from each mixture were placed for 400 days in the respective aggressive medium (sulphuric acid with a pH value of 2 or lactic acid with a pH value between 3.2 - 3.5).

pH 2 sulphuric acid

During the storage in pH 2 sulphuric acid, the pH value was kept constant via automatic titration. The aggressive solution was changed each week. The surface/volume ratio was set at approx. 11 m⁻¹ in each instance, and the solution was constantly in motion through agitators. The layer of corrosion formed on the test specimens was not removed during the weekly changes.

In addition, 4 test specimens were stored under water for the duration of the sulphuric acid corrosion period. Their compressive strength is used as the reference strength to calculate the relative change in strength when assessing the decline in compressive strength.

The storage period was not established at the beginning of the tests. To check the progress of the corrosion, the **visual corrosion depth X**_{V,t} of one test specimen from each series was determined in a sawn section after 6, 8 and approx. 12 months. After 12 months there were considerable corrosion depths, and thus the end of the storage period was set at 400 d.

pH 3.2 - 3.5 lactic acid

In addition, 4 samples of each mixture were stored under water for the duration of the lactic acid corrosion period. Their compressive strength is used as the reference strength to calculate the relative change in strength when assessing the decline in compressive strength.

Here as well, the storage period was not established at the beginning of the tests. The samples with the double screened limestone chippings and crushed sand were so obviously damaged after 6 months due to severe weathering that the storage was ended for these test specimens. The test specimens made from the inert Rhine gravel and sand exhibited much less damage. Similar to the sulphuric acid storage, the **visual corrosion depth X**_{V,t} of one test specimen from each series was determined at a sawn section after 6 and 7.5 months. After 7.5 months there were considerable corrosion depths, and thus the end of the storage was set at 8 months.

Due to the formation of organic growth, the baths were first preserved with formaldehyde and later with a formaldehyde releaser. What was striking was, that, in comparison to sulphuric acid, there was a very high level of lactic acid consumption. This mainly had to do with the high buffer capacity of the lactates that formed during storage.

After storage was over, the test specimens were scrubbed with a brush and, if necessary, with a wire brush to remove loose parts, and were photographed to document the external changes. The weathering depth in the brushed-off test specimens was determined by the change in the external dimensions. Afterwards, cylinder-shaped test specimens were sawn out of the middle of the corroded cylinders so that they were approx. 85 mm in height (according to a slenderness of 1, compared to the initial cross sections before being placed in the acid). The sawn surfaces were ground plane parallel and photographed, and the breaking load was determined after 2 days of storage at 23 °C and 50% rel. humidity. The two sections from preparing each test specimen were used for determining the penetration depth visually and microscopically.

The ability to resist the corrosive attack is assessed using **various parameters**, which are briefly described as follows.

<u>Residual compressive strength</u>: The residual compressive strength is determined by comparing the breaking loads $F_{D,acid}$ of the corroded test specimens to those of the corresponding initial cross section d_0 .

<u>Relative residual compressive strength</u>: The relative residual compressive strength is determined by comparing the average residual compressive strength of the corroded test specimens with the test specimens of the same composition that were stored in water.

The corrosion depths brought about during exposure to the acid are the key means of assessing the behaviour of the concretes being tested.

<u>Ablation depth</u> X_A : A first impression is given by the external changes through ablation that have been determined and documented with photographs.

<u>Corrosion depth determined visually on section</u> X_V : The **corrosion depth XV** determined visually on the section indicates how deep the infusing acid has visually changed the material structure, with the weathering depth factored in for the purpose of a better comparison.

<u>Corrosion depth determined using light microscopy on section</u> X_M : The corrosion depth X_M determined using light microscopy on the cross section indicates how deep the infusing acid has changed the material structure, with the weathering depth factored in for the purpose of a better comparison.

<u>Corrosion depth from residual breaking loads</u> $X_{B,D}$: The extent, or depth, to which the material structure has been affected with respect to load capacity is revealed by the special compression tests conducted on the test specimens after being exposed to acid, which is then used to calculate the **corrosion depth** $X_{B,D}$: The initial cross section of the test specimen minus the corrosion depth $X_{B,D}$ yields the uninfluenced core dimensions with respect to strength, with the strength of a test specimen of the same age – but stored in water – used as the reference for strength.

The corrosion depth is calculated from the residual breaking loads according to the following formula:

$$X_{\beta,D} = 0.5 \cdot \left[d_0 - \sqrt{\frac{F_{D,acid}}{F_{D,water}}} \cdot d_0 \right] = 0.5 \cdot d_0 \left[1 - \sqrt{\frac{F_{D,acid}}{F_{D,water}}} \right]$$

whereas: d_0 = initial diameter

F_{D,acid} = test force of the corroded core after being stored in acid

F_{D,water} = test force of the initial cross section that was stored in water

According to previous experience with mortar systems, the following is to be expected: $X_A < X_V < X_{B,D} < X_M$.

4.1.1. Determining the Compressive Strengths, Residual Compressive Strengths and the Corrosion Depth X_{B,D} after Being Placed in pH 2 Sulphuric Acid and pH 3.2 - 3.5 Lactic Acid

To determine the residual compressive strength, the breaking loads of the corroded test specimen cylinders were compared to the initial cross section surfaces before being placed in acid. Before the test, both end surfaces were sawn off of the corroded cylindrical test specimens and ground plane parallel. The test specimens had a height of approx. 85.5 mm and a slenderness of 1 compared to the cross sections before being placed in acid. The reference strengths were determined in cylinders with the same slenderness after being stored in water for the same length of time. To determine the relative percentage residual compressive strength, the strengths of the corroded test specimens were compared the strengths of those in reference storage.

4.1.2. Determining the Ablation Depth X_A

After they have been brushed off, the external dimensions of each test specimen are determined using the caliper gauge with 9 individual determinations to calculate the ablation depth (upper, middle and lower cross sections, each 3 times). The average test specimen measurement (85.5 mm) was used as the initial measurement before being placed in the acid.

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4.2. Determining the Visual Corrosion Depth Xv on the Section

The two sections from the preparation of each test specimen for the compressive strength test were used to determine the visually calculated penetration depth. In the process, the obviously non-impacted residual cross section in each section was determined 4 times with a caliper gauge so that 24 individual values were available for each test specimen series.

4.3. Microscopic Determining the Corrosion Depth X_M

One of the sections from the preparation of each test specimen for the compressive strength test was used to determine the penetration depth detectable in the grind section using microscopy. To do this, the test specimen was first pressed with EP resin. Afterwards, the sample was ground plane parallel and polished. The damage depth was determined using a light microscope at 50x and 100x magnification in incident light with a crossed analyser.

5. Test Results

5.1. Results of the Corrosion Tests after 400 Days of Storage in pH 2 Sulphuric Acid

Table 6 below shows the average values and coefficients of variation of the calculated compressive strengths and the derived parameters for assessing the corrosion resistance after 400 days of storage in pH 2 sulphuric acid. In addition, the calculated ablation depths X_A and the corrosion depths X_V , X_M and $X_{B,D}$ calculated visually, using microscopy and via the changes in the breaking loads have been compiled. What bears pointing out is the considerable increase in tensile strength of the [®]MOWILITH pipe concretes by approx. 25% (see Table 6) compared to the unmodified concretes.

The compressive and residual compressive strengths are shown in graph form in Diagram 2. The initial compressive strengths – some over 70 N/mm² – of the [®]MOWILITHmodified pipe concretes are comparable to the strengths of the unmodified concretes. After 400 days of being stored in water, considerable subsequent hardening took place, which increased the strength in the two unmodified concretes by 25% and in the [®]MOWILITH pipe concretes by 15% (limestone concrete) or by 8% (Rhine gravel concrete).

The values for the relative residual compressive strengths are shown in graph form in Diagram 3. The modification of the limestone pipe concrete with [®]MOWILITH brings about a dramatic increase in the residual compressive strength. For pipe concretes with quartzite aggregate, only a slight improvement in the relative compressive strength can be determined.

The corrosion depths determined are shown in Diagram 4. To determine the efficacy of the polymer modification, the value with the greatest damage depth was taken from the three corrosion depths determined for each concrete recipe and used for comparison. This demonstrates the considerable efficacy of the polymer additive with reactive aggregates (limestone concrete). Here, the addition of [®]MOWILITH reduced the corrosion depth by well over 50%. For concretes with inert quartzite aggregate, a 38% reduction in the corrosion depth by adding [®]MOWILITH was determined.

Table 6:Compressive strengths, residual compressive strengths, relative residual compressive strengths and
corrosion depths of the pipe concretes with CEM I 42.5 R HS NA after 400 days in pH 2
sulphuric acid or water. The storage in acid started when the test specimens were 84 days old.

	Limestone Aggregate		Rhine Gravel Aggr.					
		®MOWILITH		®MOWILITH				
	R K HS 0	R K HS I	RQHS0	R Q HS I				
Compressive strength before placement (3 values, test specimens age 84 d)								
Mean value [N/mm ²]	73.5	75.4	82.8	78.8				
Coeff. of variation [%]	12.4	1.5	1.3	1.5				
Tensile strength before	Tensile strength before placement (2 values, test specimens age 84 d)							
Mean value [N/mm ²]	5.7	7.2	5.2	6.5				
Coeff. of variation [%]	8.7	4.9	0.5	1.1				
Compressive strength a	fter placemen	t in water (4 v	alues)					
Mean value [N/mm ²]	92.9	87.3	103.5	85.5				
Coeff. of variation [%]	8.18	1.06	1.25	2.04				
Compressive strength a	fter placemen	t in acid (4 va	lues)					
Mean value [N/mm ²]	56.6	72.6	88.3	74.3				
Coeff. of variation [%]	5.1	4.2	3.3	8.1				
Relative Residual C	ompressive	Strength						
Mean value [%]	60.9	83.2	85.3	86.9				
Ablation depth X _A [exte	ernal dimensio	ns]						
Mean value [mm]	6.1	1.8	1.2	0.6				
Coeff. of variation [%]	7.2	15.7	12.5	26.8				
Corrosion depth X _V [vis	sual penetratio	on depth]		• •				
Mean value [mm]	8.4	3.3	3.9	2.9				
Coeff. of variation [%]	7.3	3.9	5.5	10.4				
Corrosion depth X _M [microscopic penetration depth]								
Mean value [mm]	9.1	4.3	4.7	2.9				
Coeff. of variation [%]	6.7	3.0	4.5	10.4				
Corrosion depth X _{B,D} [from compressive strength]								
Mean value [mm]	9.4	3.8	3.3	2.9				
Coeff. of variation [%]	15,9	22.0	19.5	54.7				



Diagram 2: Compressive strengths of pipe concretes with CEM I 42.5 R HS NA before placement, after 400 days of being stored in water and residual compressive strengths after 400 days of being stored in pH 2 sulphuric acid.



Diagram 3: Relative percentage residual compressive strengths of the pipe concretes with CEM I 42,5 R HS NA after 400 days of being stored in pH 2 sulphuric acid



Diagram 4: Corrosion depth of pipe concretes with CEM I 42.5 R HS NA determined visually and microscopically and from changes in the breaking loads after 400 days of being stored in pH 2 sulphuric acid.

5.2. Results of the Corrosion Tests after 6 or 8 months of Being Stored in pH 3.2 - 3.5 Lactic Acid

Table 7 shows the mean values, coefficients of variation of the calculated compressive strengths and the parameters derived from them for assessing the ability to resist corrosion after being placed in lactic acid at pH values between 3.2 and 3.5. In addition, the calculated ablation depths X_A and the corrosion depths X_V , X_M and $X_{\beta,D}$ determined visually and microscopically and from changes in the breaking loads are compiled.

The compressive and residual compressive strengths are shown in graph form in Diagram 5. What is remarkable is the considerable subsequent hardening of the limestone concretes after 6 months of being stored in water and of the Rhine gravel concretes after 8 months. The residual compressive strengths of the limestone concretes after 6 months of being stored in lactic acid at pH values between 3.2 and 3.5 are much less than those after 400 days of being stored in pH 2 sulphuric acid. The pipe concretes with quartzite aggregate exhibit similar residual compressive strengths after 8 months of being stored in lactic acid compressive strengths after 8 months of being stored in lactic acid compressive strengths after 8 months of being stored in lactic acid compared to after 400 days of exposure to sulphuric acid. This has to do with the fact that soluble lactates form from the lactic acid corrosion, resulting in a high buffer capacity in the solution. This leads to an overdose of undissociated lactic acid during the test, which is not recorded by measuring the pH value (i.e. the <u>free</u> concentration of hydrogen ions). In practice, such parameters also occur with other organic acids (e.g. acetic acid).

The values for the relative percentage residual compressive strengths are shown in graph form in Diagram 6. The modification of the limestone pipe concrete with [®]MOWILITH causes a drastic increase in the relative residual compressive strength by nearly 50%. For the pipe concretes with quartzite aggregate, only a slight improvement in the relative residual compressive strength can be determined – as with sulphuric acid.

The compilation of the corrosion depths in Diagram 7 highlights the clear efficacy of adding polymers with reactive aggregates (limestone concrete) for organic acids as well. In comparison to the highest damage depth of each series, a reduction in corrosion depth of around 50% through the addition of [®]MOWILITH was determined. In the concretes with inert aggregate, the [®]MOWILITH concrete exhibits the same minimal damage depth.

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Table 7:Compressive strengths, residual compressive strengths, relative residual compressive strengths and
corrosion depths of the pipe concretes with CEM I 42.5 HS NA after being stored for 6 or 8
months in lactic acid and water.

	Limestone	Aggregate	Rhine Gravel Aggr.				
	6 MO	NTHS	8 MO	NTHS			
		®MOWILITH		®MOWILITH			
	R K HS 0	R K HS I	RQHS0	R Q HS I			
Compressive strength before placement (3 values, test specimens age 84 d)							
Mean value [N/mm ²]	73.5	75.4	82.8	78.8			
Coeff. of variation [%]	12.4	1.5	1.3	1.5			
Compressive strength a	fter placemen	t in water (4 v	alues)				
Mean value [N/mm ²]	89.1	85.3	99.4	86.1			
Coeff. of variation [%]	5.9	3.3	4.0	3.2			
Compressive strength a	fter placemen	t in acid (4 va	lues)				
Mean value [N/mm ²]	29.5	50.7	84.0	73.5			
Coeff. of variation [%]	17.4	11.9	7.6	4.5			
Relative Residual C	ompressive	Strength					
Mean value [%]	33.12	59.4	84.6	85.3			
Ablation depth X _A [exte	rnal dimensio	ns]					
Mean value [mm]	13.5	4.7	0.9	0.7			
Coeff. of variation [%]	17.5	21.1	33.7	35.1			
Corrosion depth X _V [vis	ual penetratio	on depth]					
Mean value [mm]	16.6	6.5	3.8	3.5			
Coeff. of variation [%]	11.2	30.0	6.2	6.6			
Corrosion depth X _M [microscopic penetration depth]							
Mean value [mm]	17.3	7.4	4.51	4.5			
Coeff. of variation [%]	10.7	26.4	5.1	5.1			
Corrosion depth X _{β,D} [from compressive strength]							
Mean value [mm]	18.2	9.8	3.5	3.3			
Coeff. of variation [%]	10.3	17.2	42.9	27.3			



Diagram 5: Compressive strengths of pipe concretes with CEM I 42.5 R HS NA before placement, after 6 or 8 months of being stored in water and residual compressive strengths after 6 or 8 months of being stored in pH 2 lactic acid.



Diagram 6: Relative residual compressive strengths of the pipe concretes with CEM I 42,5 R HS NA after 6 or 8 months of being stored in pH 3.2 - 3.5 lactic acid.



Diagram 7: Corrosion depth of pipe concretes after 6 to 8 months of being stored in pH 3.2 - 3.5 lactic acid. The damage depth is determined visually and microscopically and from changes in the breaking loads.

6. Summary Valuation of the Test Results

The undersigned was commissioned by the company Clariant GmbH to test the extent to which the use of the concrete additive [®]MOWILITH LDM 6880 can increase the corrosion resistance of pipe concretes to acid exposure. In particular, the corrosion resistance to biogenic sulphuric acids was to be determined. In addition, the corrosion resistance to lactic acid, representing organic acids, was to be calculated.

The concrete compositions were developed jointly by the customer, the Bauberatung Zement Hamburg and the institute of the undersigned, geared towards practical requirements.

Two reference recipes without [®]MOWILITH LDM 6880, one with limestone aggregate and the other with quartzite aggregate, were prepared using a CEM 1 42.5 R HS NA cement. To verify the efficacy of the polymer modification with regard to acid resistance, a comparative recipe with the 15% [®]MOWILITH LDM 6880 construction material dispersion in relation to cement weight was used in each instance. The mixtures were set to around the same consistency. The cement content of all mixtures was kept constant at 350 kg/m³. The water portion of the dispersion was included in the mixing water; the polymer portion was factored in as aggregate in the material volume calculation.

The concretes were compacted using a high-capacity vibrating table and a preparation weight (0.02 N/mm²). The suitability of the recipes for producing pipe concretes was demonstrated by checking the green compressive strength 10 minutes after being received. All mixtures exhibited a green compressive strength greater than 0.09 N/mm². All concretes were readily able to be compacted. The good compactability of the MOWILITH-modified concretes can be emphasised.

During placement at a test specimen age of 84 days, all concretes exhibited compressive strengths of over 70 N/mm². The strength of the modified concretes was about the same for the limestone concretes and was slightly below that of the reference concretes for the Rhine gravel concretes. The tensile strengths of the modified concretes were a good 25% above those of the reference concretes.

The tests on corrosion resistance to the selected acids were conducted based on the publication "Guideline for the Testing of Mortars for Use in Sewer System Construction" [1] with pipe concretes produced in the laboratory. The duration of exposure to the aggressive media was selected depending on how the corrosion was progressing. The exposure to sulphuric acid at a pH of 2 took place over a period of 400 days. The exposure to lactic acid at pH values of 3.2 to 3.5 was completed after 6 months for the limestone concretes and after 8 months for the Rhine gravel concretes.

During exposure to sulphuric acid with a pH value of 2 over 400 days, a high efficacy of the polymer addition was determined for the limestone concretes. The corrosion depth was reduced by more than 50% through the [®]MOWILITH additive. For the concretes with inert quartzite aggregate, a 38% reduction in the corrosion depth was determined after adding [®]MOWILITH.

During exposure to lactic acid with pH values between 3.2 and 3.5 over 6 months, a high efficacy of the polymer addition was also determined for the limestone concretes. The corrosion depth was reduced through the [®]MOWILITH additive by about 50%. The concretes with inert quartzite aggregate exhibited the same corrosion depths as the reference concretes after 8 months through the [®]MOWILITH additive.

7. Signature

21071 Hamburg, 31 August 1998

[signature]

Prof. Dr.-Ing. Lutz Franke

8. Appended Images



Image 1: External changes to the series **R K HS 0** after 400 days in pH 2 sulphuric acid.



Image 2: External changes to the series **R K HS 1** after 400 days in pH 2 sulphuric acid.



Image 3: External changes to the series **R Q HS 0** after 400 days in pH 2 sulphuric acid.



Image 4: External changes to the series **R Q HS 1** after 400 days in pH 2 sulphuric acid.



Image 5: External changes to the series **R K HS 0** after 6 months of being stored in pH 3.2 to 3.5 lactic acid



Image 6: External changes to the series **R K HS 1** after 6 months of being stored in pH 3.2 to 3.5 lactic acid

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Image 7: External changes to the series **R Q HS 0** after **8 months** of being stored in pH 3.2 to 3.5 lactic acid



Image 8: External changes to the series **R Q HS 1** after 8 months of being stored in pH 3.2 to 3.5 lactic acid

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9. Literature

¹ Franke, L., Oly, M. and Pinsler, F.: *Richtlinie für die Prüfung von Mörteln für den Einsatz im Sielbau.* Tiefbau Ingenieurbau Strassenbau, 4, **1997**, 19-23